II. *A Diſcourſe concerning ſome Influence of* Reſpiration *on the* Motion *of the* Heart, *hitherto unobſerved.* *By* J. Drake, M. D. F. R. S.

THo divers accurate Treatiſes of the *Heart*, and its action, have been written by Learned Men of ſeveral Nations, eſpecially by two of our own Country; the Great *Dr Harvey*, to whoſe happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable *Dr Lower*, to whom we are beholding for a compleat diſplay of the *Mechanical Structure* of the *Heart*, and a moſt ingenious Rationale of its Action. Yet there remain ſeveral doubts and difficulties about it (in my opinion) not ſufficiently accounted for, towards the reſolving ſome of which I ſhall offer what my own thoughts have ſuggeſted to me, and leave it to the conſideration of the Reader.

The Learned *Dr Lower* (whoſe accurate piece on this Argument will inſure his Reputation ſo long as Phyſical knowledge ſhall laſt in eſteem) has ſo well accounted for the *Syſtole*, or Contraction of the Heart from the *Mechanical* Structure of it, that he ſeems almoſt to have exhauſted the ſubject, and had he been as happy in diſcovering the true cauſe of the *Diaſtole*, he had left little room for the Induſtry and Sagacity of others about this *Viſcus*.

But having judiciouſly and ſolidly explain'd the *Syſtole*, he contents himſelf to aſcribe the *Diaſtole* to a motion of *Reſtitution*, which account gives me no ſatisfaction: Becauſe the *Syſtole* being the proper, and (as himſelf confeſſes) the only motion of the Heart, a ſtate of *Contraction* ſeems to be the natural ſtate, and conſequently without external violence, it ſhou'd have no *Diaſtole* at all.

This will appear more plain, if we conſider the circumſtances of it, and its motion, as a Muſcle, with reſpect to other Muſcles. That Contraction is the proper Action, and ſtate of all Muſcles, is evident from Experience of Fact, as well as Reaſon. For, if any Muſcle be freed from the power of its *Antagoniſt*, it is immediately *contracted*, and is not by any action of the Will, or Spirits to be reduc'd to a ſtate of *Dilatation*. Thus, if the *Muſculi Flexores* of any Joint be divided, the *Extenſores* of that Joint being by that means freed from the contrary Action of their *Antagoniſts*, that Joint is immediately extended without any conſent of the Will, and in that ſtate it remains; and ſo *Vice verſâ* if the *Extenſores* be divided. From whence it is plain, that the Muſcles have no reſtitutive motion, but what they derive from the Action of their *Antagoniſts* by which they are ballanc'd. Thus likewiſe the *Spincters* of the *Gula*, *Anus* and *Veſica*, having no proper *Antagoniſts*, are always in a ſtate of Contraction, and ſuffer nothing to paſs 'em, but what is forced thro 'em by the contrary Action of ſome ſtronger Muſcles, which, tho not properly to be call'd *Antagoniſts*, yet on all neceſſary occaſions perform the office of ſuch.

That the Heart is a Muſcle, furniſh'd and inſtructed for motion like other Muſcles, is (in my opinion at leaſt) demonſtrated beyond contradiction by Dr *Lower* and others. And, as it is a *Solitary* Muſcle without any proper *Antagoniſt*, and not directly under the power of the Will, nor exerciſing *Voluntary* motion, it approaches neareſt to the *Sphincter* kind, which only has theſe conditions in common with it. But in conſtant and regular alternations of Contraction and Dilatation, it differs exceedingly from all the Muſcles of the Body.

This *reciprocal Æſtus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the ſtructure, which ſhou'd neceſſarily occaſion it, nor any

Antagoniſt, whoſe re-action ſhou'd produce it, have been extreamly perplext to find out the cauſe of it.

But paſſing over the various opinions of Authors, to avoid being tedious, I ſhall take notice here only of the very Learned Dr *Lower*'s, in whoſe account of the *Syſtole*, however ſolid and ingenious, I obſerve ſomething deficient, and whoſe *Hypotheſis* of the *Diaſtole* I think to be precarious and falſe.

This excellent Author, having by ſound Arguments, drawn from the Structure and Mechaniſm of the Heart, eſtabliſht the certainty of its *Muſcular* Motion, reſts ſatisfied, without taking notice of any Aſſiſtance, that the Heart receives from any other Part, except from the Brain, by the means of the eighth Pair of Nerves.

The Accurate *Borellus* in his *Oeconomia Animalis* computes the *Motive* Power of the *Machine* of the Heart to be *Part 2d.*
equal to, or to ſurmount that of a Weight of 3000 *l.* The *Prop.* 67. *Prop.* 73.
Obſtacles to the Motion of the Blood thro the *Arteries* he eſteems equivalent to 180,000 *l.* which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000 *l.* for the Adventitious Help of the *Muſcular Elaſtick Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000 *l.* *Prop.* 76.
to overcome a reſiſtance of 135,000 *l.* that is, with 1 to remove 45.

This ſtupendous effect he contents himſelf to aſcribe to the *Energy* of *Percuſſion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain conſtantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percuſſion* does either not reach at all, or but very languidly, he might probably have ſeen a neceſſity for ſome other Expedient to remove ſo inſuperable a difficulty.

But not to inſiſt rigorouſly on the exactneſs of this Calculation (tho the great Abilities of the Author in this way, and his Ingenuity and Modeſty, are a ſufficient Warrant for the accuracy of his Computations, and the fidelity of his Accounts) we may allow a much greater Deduction, than would be juſtifiable, without leſſening the difficulty. But this account I have taken notice of purely for the ſake of the Calculation, which may be of uſe in the Sequel, the account it ſelf being in other reſpects more defective than Dr *Lower*'s, to which we will return.

The Dr, notwithſtanding his great Sagacity, appears (to me) to have overlookt ſomething of very great moment, and importance in the explication of the Action of the Heart. For, tho it ſhou'd be granted, that the *Muſcular Fibres* of the Heart acted by the Nerves, are the immediate Inſtruments of its *Conſtriction* or *Syſtole*, yet it muſt not be denied, that the *Intercoſtal* Muſcles and *Diaphragm* are of great ſervice to aid and facilitate this Contraction, by opening a Paſſage for the Blood thro the Lungs, which denied wou'd be an invincible obſtacle.

Neither do they promote it that way only. The manner how they farther aſſiſt the Heart in its Contraction, will appear manifeſtly, if we conſider the different Poſture, Scituation and Capacity of the Blood Veſſels of the Lungs in the ſeveral times of *Elevation* and *Depreſſion* of the *Coſtæ*.

The *Pulmonary* Artery riſes from the *right* Ventricle of the Heart, and runs in one Trunk, till it comes to the *Aſpera Arteria*, where it is divided, and ſends a Branch along with each diviſion of the *Aſpera Arteria*, according to all the minuteſt ſubdiviſions, of which it is likewiſe ſubdivided, accompanying all the *Bronchi*, in their whole progreſs thro the Lungs.

The *Pulmonary* Vein, which empties it ſelf into the *Left* Ventricle of the Heart, ſpreads it ſelf on the *Aſpera Arteria* and *Bronchi*, in the ſame manner that the Artery does.

The neceſſary conſequence of this diſpoſition is, that this Artery and Vein being coextended with, and faſten'd to the *Bronchi*, muſt needs ſuffer ſuch alteration of *Superficial* Dimenſions, as the *Bronchi* do in the *Elevation* or *Depreſſion* of the *Coſtæ*.

While the Ribs are in a ſtate of *Drepreſſion* (whether before Commerce with the external Air or after) the *Annular Cartilages* of the *Bronchi* ſhrink one into another, and by that means their *Dimenſions* are exceedingly contracted. In conformity to this condition of the *Bronchi* the *Pulmonary* Artery and Vein muſt likewiſe, either by means of their *Muſcular* Coats contract themſelves to the ſame *Dimenſions*, or lye in *Folds* or *Corrugations*, which is leſs probable.

On the other hand, when the Ribs are elevated, and the *Diaphragm* bears downward, the Air ruſhing into the Lungs, ſhoots out the *Cartilaginous* Rings, and *Divaricates* the Branches of the *Trachea*, and by them extends and divaricates the ſeveral diviſions of the *Pulmonary* Artery and Veins, and thereby lengthens and enlarges their Cavities.

This enlargement of their Cavities is very conſiderable, not only upon the ſcore of the addition, which they receive in length thereby, but alſo upon the account of their *Divarication*. For whereas, when the Ribs are depreſt, and the Lungs ſubſide, the Blood Veſſels are not only contracted, (as I have already obſerv'd) but their Branches, which are exceeding numerous, approach one another, and lie in juxta-poſition, by which their Cavities are very much compreſs'd and ſtreighten'd : when the Ribs are elevated, and the Lungs turgid with Air, not only the Fibres, by which their Coats in the oppoſite State were contracted, are extended, but thoſe innumerable Veſſels, which lying before in lines almoſt parallel upon one another, compreſs'd one another, making an *acute* Angle at their Junctures, are divaricated and ſeparated from each other, and make an *obtuſe*, whereby their Channels are widen'd.

Thus a paſſage is open'd to the Blood, from the *Right* Ventricle of the Heart to the *Left*, thro the Lungs, to which it cou'd not otherwiſe paſs ; and the oppoſition, which the Blood, contain'd in that Ventricle, muſt otherwiſe neceſſarily have made to its conſtriction, is taken off, and the *Syſtole* thereby facilitated.

Nor is that all. For the *Diaſtole* being caus'd (as I ſhall in the ſequel ſhew) by the Force of the Blood ruſhing into the Ventricles, this Ampliation and Extenſion of the *Pul-*

monary Artery is a ſort of *Check* or *Counterpoiſe* to it, and prevents an endeavour towards two contrary Actions at once, which muſt neceſſarily fruſtrate both. For the Heart being a *Springy*, *Compreſſible* Body, whoſe proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibres, or Subſtance ; and containing beſides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Veſſel muſt in great meaſure reſemble that of a *Syringe*, whoſe extremity is immers'd in Water, the Enlargement or Expanſion of the Channels of the Artery anſwering the drawing of the *Embolum*, as the Conſtrictive Motion of the Muſcle of the Heart does the Preſſure of the *Atmoſphere* upon the *Surface* of the Water, the one making way for the fluid, and the other forcing it to follow, where the reſiſtance is leaſt. In this ſenſe we may allow a ſort of Attraction to the *Pulmonary* Artery, depending wholly upon the Action of the *Intercoſtal* Muſcles and *Diaphragm*, which we muſt therefore confeſs to be very ſerviceable and inſtrumental in promoting the *Syſtole* of the Heart.

But if the Learned Author be deficient in his account of the *Syſtole* ; that is, if he has not obſerv'd all the Mechaniſm and Contrivance of Nature for the Contraction of the Heart ; much leſs ſufficiently has he accounted for the *Diaſtole*, or Dilatation of it, which he aſcribes to a Motion of *reſtitution* of the over-ſtrain'd Fibres, which yet he confeſſes are made for *Conſtriction* only. 'Tis true, he immediately after joyns the *influx* of the *Blood* as a concurrent cauſe ; but from the ſlight notice that he takes of it, 'tis plain, that he did not ſo much as dream of any great ſhare it had in that action. His words are theſe.

De Corde Pag. 75.

Quin & (ut obiter hoc moneam) cum omnis motus contractione perficiatur, & Cordis Fibræ ad conſtrictionem ſolum factæ ſint, apparet quoque Cordis motum totum *in* Syſtole *poſitum eſſe ; cumq; Fibræ ultra tonum ſuum in omni conſtrictione ejus tendantur, idcirco ubi nixus iſte abſolvitur, motu quaſi* reſtitutionis *Cor* *iterum relaxatur, & ſanguine a Venis* influente *rurſus diſtenditur*; *a* nullo *enim cordis motu, niſi* tenſionem ſuam remittente, *& ab* irruente *ſanguine* Diaſtole *ejus libratis adeo viribus ſuccedit.*

I have tranſcribed the entire Paragraph, becauſe it contains his whole *Hypotheſis* of the *Diaſtole*, and all the notice that he takes of it thro his whole Work. But how ſlender ſoever this may prove, it is the moſt ſubſtantial that I have any where met with, except a late one of Mr *Cowper*, which is properly an improvement of this, and ſhall be conſidered in the ſequel.

But, if Contraction be the ſole Action of theſe Fibres (as this Great Man confeſſes it to be) and as indeed it is of all *Muſcular* Fibres, I wonder how ſo judicious a Writer came to ſlip into ſuch an abſurdity, as to call their Diſtenſion (vulgarly but improperly called Relaxation) a Motion of *Reſtitution.* For from the Nature of thoſe Fibres, and their diſpoſition in the Structure of the Heart, the Natural State of the Heart appears manifeſtly to be *Tonical*, and its Dilatation a State of Violence; and conſequently the Conſtriction is the *true* motion of *Reſtitution*, and the State to which it will *ſpontaneouſly* return, when the Force is taken off, which is the work of the *Intercoſtal* Muſcles and *Diaphragm.*

Thus we are left ſtill to ſeek for the true cauſe of the *Diaſtole*, which ſeems to me to be the main and moſt difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr *Cowper*'s ingenious *Introduction* to his *Anatomy of Human Bodies*, I find the Share which *Dr Lower* hints the Blood to have in that Action, further proſecuted, and improv'd into the main Inſtrument of the Dilatation of the Heart, wherein I agree entirely with him. But as to the manner, and reaſons of its being ſo very Inſtrumental, I can't be ſo perfectly of his mind.

The Heart (ſays this accurate Anatomiſt) *of an Animal bears a great Analogy to the Pendulums of thoſe Artificial*

Automata, Clocks and Watches, whilſt its Motion is performed like that of other Muſcles, the Blood doing the Office of a Pondus.

This Explication, being but a Simile without a diſtinct application to particulars, is beſide ſo very ſhort, that I can at beſt but give a conjecture at the meaning, which if I miſtake, I ſhall deſerve to be excuſed, and expect to be better inform'd.

By the *Blood*'s doing the Office of a *Pondus*, I ſuppoſe he means, that the Blood contributes in the ſame manner to the Motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If ſo, the Blood, according to him, muſt be the Inſtrument of *Conſtriction*; and *Dilatation* muſt be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no Violence, return; the contrary of which, I preſume, will appear e're I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoiſe* to its contraction as a Muſcle, I cou'd wiſh his deſign had not bound him up to ſo narrow a compaſs, and that he had given us an explication at large of ſo abſtruſe and ſo important a *Phænomenon*. Becauſe the *Specifick Gravity* of the Blood ſeems to me a cauſe by no means alone adequate to the effect, which it is here ſuppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which deſcends from the Parts above the Heart can be employ'd in that action. This at the largeſt computation can't amount to five pound weight, and muſt, according to the computation of *Borellus*, force a Machine, that is able to overcome a reſiſtance of 135,000*l.* I leave every man to deduct what he ſhall upon examination find reaſonably to be deducted, and yet ſhall reſt ſecure, that it is not to be effected in the leaſt with ſo ſmall a Weight.

But neither does the *Refluent* Blood gravitate in any ſuch proportion, as I have here aſſign'd. For to make a true eſtimate of its *Gravitation*, we muſt conſider the circumſtances of the Liquor ſuppos'd to gravitate; in which it very much reſembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be ſuſpended in the Air full of Water, with the Extremities downwards, without loſing a drop, altho the *Diameter* of thoſe Legs ſhou'd be very unequal. The Caſe of the Arteries and Veins is pretty near a parallel to a Tube, ſo fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microſcope they are made to appear) then ſuppoſing their contents to have no other determination of Motion, than their own weight wou'd give 'em, the contain'd Fluids muſt be counterpoiſes to each other. For the Veins and Arteries being join'd at the ſmaller extremities, and the larger of both terminating in the ſame Parallel Line, it is impoſſible, according to the Laws of *Hydroſtatics*, that the contents of either ſhou'd overballance t'other. How far then muſt it fall ſhort of forcing the natural Power and Reſiſtance of ſo ſtrong a Muſcle as the Heart, by meer Gravitation.

The Blood indeed has a *Progreſſive* Motion thro its Veſſels, wherein it differs from Water, in a recurve Tube, in the experiment above ſtated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this Progreſſive Motion will not be found much more ſufficient. For, as this Motion is deriv'd entirely from the Heart's Conſtriction (as all accounts hitherto derive it) cou'd the Blood be ſuppos'd to re-act upon the Heart, with all the force firſt impreſs'd upon it by the Heart, it wou'd be inſufficient, unleſs we will ſuppoſe the *Force communicated* to be ſuperiour to the *Power Communicant*, which is abſurd.

But when the juſt and neceſſary Deductions for the Impediments, which the Blood meets with in its Progreſs thro the Veſſels, ſhall be made, the remaining Force will be found ſo exceeding weak, that to prop the Blood thro the Veins may be a task alone too great for ſo ſmall a Power, without charging it with the additional difficulty of forcing the Muſcle of the Heart.

Alphonſus Borellus, after a great deal of ſolemn pains taken to ſhew his care and exactneſs, and to poſſeſs his Reader of the truth of his Calculations, caſts up the Force of the Heart, and the *Muſcular* Coat of the Arteries, to be together equal to a weight of 3,750 *l.* and allots 'em a Reſiſtance equal to 180,000 *l.* to overcome which is 45 to 1. To make up for a diſproportion, by his own confeſſion, incredible to thoſe who have not conſidered the matter as he had done, he flings into the Scale the additional *Force of Percuſſion*, which he leaves *indefinite*, and thinks ſufficient to *force any quieſcent finite Reſiſtance whatſoever.*

But as this Acconnt and *Hypotheſis* are part of a Poſthumous Work (if a liberty of Conjecture may be allow'd in ſo uncertain a matter,) I ſhou'd ſuſpect, that theſe Papers were left unfiniſht by *Borellus*; or at leaſt, that in many places the laſt hand was never put to 'em. For, neither in this Place, nor any other of this Work, does he account for any more than the *Syſtole* of the Heart, and the reſiſtance which is made to the Progreſſive Motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart ſo prodigiouſly, that he ſeems to ſhuffle it off his hands with a general and precarious Solution, as a difficulty that he was deſirous to be rid of. For, having aſcrib'd this *ſtupendous* (as he himſelf calls it) effect to the *Energy of Percuſſion*, he takes no care to ſatisfie his Reader any farther about it, or to refer him, or give him the expectation of ſatisfaction any where elſe; altho he has an expreſs Treatiſe on the *Force of Percuſſion*, which was written preparatory to this, and to which he frequently refers in other Places of this Work. But what confirms my ſuſpicion, that this part was intended for a farther Reviſe by the Author, is, that he has left the Progreſs of the Blood thro the Veins, and the *Diaſtole* of the Heart, abſolutely untouch'd, tho they are difficulties of a much greater Magnitude, than this which he has attempted to account ſo ſlightly for. For, in theſe he is excluded the benefit of *Percuſſion*, and has yet a greater reſiſtance to overcome without it. Omiſſions of this kind are ſo unuſual with this Author, where-ever he knows himſelf to go upon ſure grounds, that it is to me an Argument, that he doubted the ſufficience of his *Percuſſion*, and reſerv'd theſe important *Phænomena* for farther conſideration, without plunging himſelf into ſuch an Abſurdity as to aſcribe to *Percuſſion* any ſuch *Energy* as to be able (ſo broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at firſt deriv'd.

Dr *Lower* and Mr *Cowper* deliver their Opinions of the Cauſe of the Dilatation of the Heart ſo very ſhort, and without any Arguments to ſupport 'em, that by expoſing 'em naked, they ſeem rather to diſcourſe of it tranſiently, as men obliged by the nature of their Subjects to ſay ſomething of it, than ſolicitous to give any full or ſatisfactory Account, and therefore I ſhall proceed no farther upon 'em here.

But tho the *Hypotheſis* of *Borellus* may in this caſe be found precarious or inſufficient (a misfortune that has befallen him in divers other particulars) his *Theory* holds ſtill good. At leaſt it ought to be allowed in juſtice to his great Abilities and Exactneſs, till ſome body convicts him of ſome material Error in his Calculations, which has not as yet been done by any body, that I know of.

Suppoſing then the Force of the Heart, and of the *Muſcular* Coat of the Arteries, as likewiſe of the reſiſtance, which they muſt overcome, to be computed with any degree of accuracy, there remains yet ſuch a prodigious diſproportion to be accounted for, as requires ſome more powerful Agent, than any yet aſſign'd, to make up the deficiency.

What aſſiſtance the Heart receives from the action of the *Thorax* towards the facilitating its contraction, without which aſſiſtance there cou'd have been no *Syſtole*, has been already ſhewn. But neither the *Intercoſtal* Muſcles, or *Diaphragm*, which are ſo inſtrumental in that part of its action, can contribute any thing to the *Diaſtole*; becauſe they ſerve only to enlarge the cavity of the *Thorax*, and thereby to open a Paſſage to the Blood from the Heart, and promote its Conſtriction.

Whatever therefore the Force is, that dilates the Heart, and is the Cauſe of the *Diaſtole*, it muſt be equal to that of the Heart, the *Intercoſtal* Muſcles and *Diaphragm*; to all which it acts as an Antagoniſt. I take no notice of the *Serratus Major Anticus*, and other Muſcles, which have an obſcure ſhare in the *Elevation* of the *Coſtæ*, becauſe as much may reaſonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muſcles; which, having their inſertions on ſome of the lower *Ribs*, are as inſtrumental towards the *Depreſſion* of 'em, and ſo ballance the account. But the chief uſe of theſe is in violent Reſpiration. In ordinary Reſpiration their ſhare is ſmall.

Such a real Power (which may in the leaſt be ſuſpected of any ſhare in this Action) is hard, perhaps impoſſible to be found in the *Machine* of any *Animal* Body; and yet without ſome ſuch Antagoniſt,it is as impoſſible the Circulation of the Blood ſhou'd be maintain'd. All the Engines yet diſcover'd within the Body conſpire towards the *Conſtriction* of the Heart, which is the *State* of *Quieſcence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon neceſſity, becauſe upon this *Alternation* depends all Animal Life.

Some ſufficient Cauſe external muſt therefore be found, to produce this great Phænomenon, which Cauſe muſt be either in the *Air*, or *Atmoſphere*, becauſe we have no conſtantt and immediate Commerce with any other *Mediams*.

Some great Phyſicians obſerving this, and that depriv'd by whatſoever Means of Communication with the *external* Air, we became inſtantly extinct, have imagin'd, that in the Act of Inſpiration certain purer parts of the Air mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nouriſh'd a ſort of *Vital Flame*, which was the cauſe of this reciprocal *Æſtus* of the Heart. Others not quite ſo groſs, rejecting an *Actual* Flame, have fancied that theſe fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Efferveſcence* which dilated it. But theſe Fancies have been long ſince exploded and condemn'd upon ample Conviction, and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not.

But ſuppoſing that ſome Air may inſinuate it ſelf into the *Pulmonary* Vein, it can no other way dilate the Heart than by an Efferveſcence in the Left Ventricle, which wou'd not dilate the Right. But this opinion is contradicted by *Autopſie*, and too laboriouſly confuted by others, to be brought upon the Stage again here.

There remains therefore only the *groſs Body* of the *Atmoſphere* to be conſider'd, which is undoubtedly the *true Antagoniſt* to all thoſe Muſcles, which ſerve for ordinary Inſpiration and the Conſtriction of the Heart. This will appear more evidently, if we conſider not only the Power, but the neceſſity of its Action upon *Animal* Bodies, as well as the want of other ſufficient Agents.

The Heart is a *Solitary* Muſcle of very great ſtrength, and the *Intercoſtal* Muſcles and Diaphragm, which likewiſe have no *Antagoniſts*, are a vaſt additional Force, which muſt be ballanc'd by the contrary action of ſome equivalent Power or other. For, tho the Action of the *Intercoſtal* Muſcles be voluntary, that does not exempt 'em from the condition of all other Muſcles ſerving for *voluntary* Motion, which wou'd be in a State of perpetual contraction, notwithſtanding any Influence of the Will, were it not for the libration of *Antagoniſt* Muſcles. This libration between other Muſcles is anſwer'd by the *Weight* of the incumbent *Atmoſphere*, which preſſes upon the *Thorax* and other Parts of the Body. And, as in all other voluntary Motions the influence of the Will only gives a Prevalence to one of two Powers before equilibrated, ſo here it ſerves to enable thoſe Muſcles to lift up a Weight too ponderous for their ſtrength not ſo aſſiſted; and therefore as ſoon as that aſſiſtance is withdrawn, the *Coſtæ* are again depreſs'd by the meer *Gravitation* of the *Atmoſphere*, which wou'd otherwiſe remain elevated thro the natural tendency of thoſe Muſcles to contraction.

This is evidently prov'd from the *Torricellian* experiments, and thoſe made upon Animals in *Mr Boyle*'s Engine; where, as ſoon as the Air is withdrawn, and the *preſſure* thereby taken off, the Intercoſtal Muſcles and Diaphragm are contracted, and the Ribs elevated in an inſtant, and can't by any power of the Will be made to ſubſide, till the Air is again let in to bear 'em forcibly down.

De Reſpirationis Organis & Uſu.

It were ſcarce worth while to take notice here of a Miſtake of the Learned Dr *Willis*, were it not for the Great Authority of the Man, which is almoſt ſufficient to keep Error in countenance. The Dr having obſerv'd that the Fibres of the *External* and *Internal Intercoſtal* Muſcles ran in a contrary order, as it were, decuſſating each other, takes occaſion from thence to fancy, that there was an oppoſition in their Office, and that as the *External* ſerv'd to raiſe up the Ribs, the *Internal* drew 'em down again, forgetting at that time, That, when a contractile Body is faſten'd at the ſeveral ends to Points unequally movable, let the Contraction happen in what part or manner ſoever, the more movable Point muſt be drawn towards the leſs movable: By which rule, whether *External* or *Internal Intercoſtals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up.

As in the Elevation of the *Coſtæ*, the Blood, by the paſſage that is open'd for it, is in a manner ſollicited into the Lungs, ſo in the Depreſſion of 'em, by the ſubſidence of the Lungs and the Contraction of the Blood Veſſels, both which are conſequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, thro the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compreſſion* of the *Body* by the *weight* of the *Atmoſphere*, which ſurrounds and preſſes upon the whole Surface of it, is that Power which cauſes the Blood to mount in the Veins, after the force impreſs'd upon it by the Heart is broken and ſpent, and which is ſufficient to force the Heart from its natural State to dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a Power ſufficient for the Effects, which are here aſcrib'd to it. And, when he conſiders, that the Bodies of Animals are compreſſible Machines, he will find that it muſt of neceſſity affect them in the manner here laid down. But tho our Bodies be entirely compos'd of *Tubuli*, or Veſſels fill'd with Fluids, yet this Preſſure, how great ſoever, being equal, cou'd have no effect upon 'em, if the ſuperficial Dimenſions were not eaſily variable; becauſe being compreſs'd on all parts with the ſame degree of Force, the contain'd Fluids cou'd not any where begin to recede, and make way for the reſt to follow, but wou'd remain as fixt and immovable as if they were actually ſolid. But by the Dilatation of the *Thorax*, room is made for the Fluids to move, and by the Coarctation of it freſh motion is impreſt, which is the main Spring whereby the Circulation is ſet and kept going.

This reciprocal Dilatation and Contraction of the Superficial Dimenſions of the Body ſeems ſo neceſſary to Animal Life, that there is not any Animal ſo imperfect as to want it, at leaſt none to the inward Structure, of which our Anatomical Diſcoveries have yet reach'd. For, the moſt kinds of *Fiſh*, and *Inſects*, wants both *moveable* Ribs, and Lungs, and conſequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechaniſm, anſwering ſufficiently the Neceſſities of their Life.

Thoſe Fiſhes, which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood Veſſels* ſuffer the ſame Alteration of Dimenſions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air Veſſels* of Inſects are yet exceedingly more different in Structure, Diſtribution and Scituation from thoſe of perfect Animals, than thoſe of Fiſhes are, and yet in their Uſe and Action agree perfectly with both, that is, *receiving* and *expelling* the Air, and *varying* the *Dimenſions* and *Capacities* of the *Blood Veſſels*. Theſe having no *Thorax*, or ſeparate Cavity for the Heart and Air Veſſels, have the latter diſtributed thro the whole Trunk of their Bodies, by which they communicate with the *External* Air thro ſeveral *Spiracula* or *Vent Holes*, to which are faſten'd ſo many little *Tracheæ*, or Wind-pipes, which thence ſend their Branches to all the Muſcles, and *Viſcera*, and ſeem to accompany the Blood Veſſels all over the Body, as they do in the Lungs only of Perfect Animals. By this diſpoſition in every *Inſpiration*, the whole Body of theſe little Animals is inflated, and in every *expiration* compreſs'd, and conſequently the Blood Veſſels muſt ſuffer a *viciſſitude* of Extenſion and Conrraction, and a greater motion muſt thereby be impreſs'd upon the Fluids contain'd in 'em, than the Heart, which does not in theſe Creatures appear to be Muſcular, ſeems capable of giving.

The only Animal that is exempted from this neceſſary condition of *Breathing*, or *receiving* and *expelling alternately ſome fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought ſcarce to be reckon'd among the number of *Animals*. For, were it not for that ſmall ſhare of *Muſcular* Motion, which it exerciſes in the Womb, it might without abſurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate matter, and means of Life, and Nutrition, Authors are not agreed, nor is it the buſineſs of this place to reconcile, or decide their differences, but to account for the motion of the Blood thro the Veſſels only. In order to this, it will be neceſſary to obſerve, that the Pulſation of the Heart in a *Fœtus* is ſo very weak and obſcure, and the motion of the Blood ſo extream ſlow and languid, as to be ſcarce, if at all, perceivable, as has been experienc'd in the Diſſection of Puppies before Reſpiration had. To produce ſuch a feeble Palpitation, and creeping Motion, no greater force ſeems to be requir'd than may be deriv'd from the Communication between the Veſſels of the Mother and *Fœtus* in the *Placenta*. I am not ignorant, that divers very Learned Anatomiſts (whom the Crowd have implicitly follow'd) have abſolutely rejected all Communication between theſe Veſſels. But, with ſubmiſſion to Great Authorities, I think they have acted arbitrarily, and without ſufficient Warrant from Reaſon or Experiment. For neither are the Arguments which they bring againſt it concluſive, nor the Office which they aſſign to the Umbilical Veſſels in lieu of it, proper, or natural to thoſe Veſſels, or the reality of the Fact made out by any ſubſtantial Reaſons. Thoſe that reject this Communication uſually do it in favour of one or both of theſe Opinions, that the Arteries of the *Uterus* do depoſite a Nutritive Juice, or a Juice impregnate *with Air* in the *Placenta*, which is ſuck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the neceſſary Uſes of Nutrition and Life. Now thoſe that patronize either of theſe Opinions lead Nature an unneceſſary dance. For if the *Maternal* Blood does really contain any ſuch *Nutritious*, or any ſuch neceſſary *Aerial* Particles, why ſhou'd they be ſeparated and extravaſated, to be with difficulty receiv'd into the *Umbilical* Vein, and again mixt with

Boyle *of the Elaſticity of Air.*

Pechlinus de Aeris & Alimenti defectu.

the Blood, when they might more eaſily have been imparted by the plain ſimple way of Transfuſion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the courſe which Nature takes in this caſe, I am perſwaded from the eaſineſs and ſimplicity of the Method, which readily performs what might be perhaps in vain expected from t'other, and wou'd over and above find 'em, what they ſeem to grope ſo blindly about for, a firſt Mover of the Blood in a *Fœtus*.

Thoſe that contend for the conveyance of a *Nutritious* Juice, thro the *Umbilical* Vein from the *Placenta*, are forc'd upon two difficulties next to Abſurdities. For firſt, they are oblig'd to make this Vein, which, as all other Veins, ſeems dedicated to the re-conveyance of Blood only, the proper and immediate Channel, thro which a very different Liquor is to be carried; and next to give a Power of Attraction or Suction to it; becauſe the *Nutritious* Juice, which it is thus deſtin'd to carry is both Viſcous and Stagnant, and has neither force to drive, nor ſubtilty to penetrate, or inſinuate it ſelf into the Capillary Veins; and therefore muſt be drawn or ſuckt as *Milk* is from the *Breaſt*, to which the *Placenta* and its *Nutritious* Juice are by the favourers of 'em expreſly compared. But if this were the ſole uſe of the *Placenta*, and *Umbilical* Veſſels, why were the Umbilical *Arteries* ſent along with the Vein? Their buſineſs is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother*; for the *Uterine* Arteries bring all to the *Placenta*, the Umbilical Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mothers* Blood; the Umbilical *Arteries* only, have nothing to do, and are ſuperfluous and impertinent, which is contrary to the conſtant practice of Nature. Yet if *Autopſie* did in the leaſt countenance this Hypotheſis, ſome defence might ſtill be made; but we find in the Umbilical *Vein* of a *Fœtus* nothing but *Florid* Blood, ſuch as in all probability it received immediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this opinion engages its favourers in ſome Abſurdity, without Neceſſity and without Proof.

They that from the *Placenta* ſupply the Body of the *Fœtus* with *Air*, are as much diſtreſs'd as t'other, for they are forc'd to beg the queſtion twice, which, even when granted, will not anſwer their ends. Firſt, they ſuppoſe, that an intimate mixture or confuſion of *Air* with the *Blood*, is neceſſary for the ſupport of Animal Life, a *Poſtulatum*, which perhaps the former part of this Diſcourſe may have render'd unneceſſary ; and next that the *Fœtus* is ſupplied with *Air* from, and its *Blood* mixt with it in the *Placenta*.

But here again they fetch a Compaſs without neceſſity or proof. For if a mixture of *Air* were neceſſary to a *Fœtus*, why ſhould it be ſeparated from the *Mothers* Blood, and not rather both communicated together, ſince it is ſo much more eaſie and commodious. But neither does the *Placenta* ſeem to be inſtructed and provided for the ſeparation of *Air*, but of a much *groſſer Fluid*, deſtin'd to ſome other uſe, which *Autopſie* confirms. Yet were both theſe opinions true, they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfuſion* this great Phænomenon is naturally accounted for, and the ends, for which the other two Hypotheſes were deviſ'd, might both be anſwered with more eaſe. For the *Hyſterick* Arteries tranſmitting their Blood immediately to the *Umbilical* Vein, may very eaſily tranſmit ſuch *Nutritious* Juices or *Aerial* Particles as are contain'd in the Blood, along with it, without depoſiting 'em by the way. By this means ſo much of the Impulſe of the Mothers Blood is preſerv'd, as ſuffices to maintain that languid circulation, which a *Fœtus* enjoys. For the Blood being driven thro' the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*,

and

and thence by a ſhort and direct paſſage thro' the *Cava* to the Heart; where paſſing thro the *Foramen Ovale* to the *Left* Ventricle, and thro the *Canalis Arterioſus* from the *Right* and *Pulmonary* Artery, it is all deliver'd without coming at the *Lungs*, to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a ſort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is favour'd by the ſtructure and diſpoſition of the Blood Veſſels on both parts, ſo there is nothing in it difficult to be conceiv'd, or repugnant to experience. Late diſcoveries have made it appear, that the Arteries and Veins are continued Tubes, and that the latter contain nothing but what they receive from the former, and no reaſon appears why we ſhou'd think this Method to be varied in the *Placenta*. On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *ſame* part, and thoſe of the *Fœtus* in like manner, without communicating with each other, their confluence in the *Placenta* ſeems to be altogether impertinent and of no uſe, and the *Umbilical* Arteries and Vein fram'd for no other ſervice or purpoſe, than to give the Blood room for an idle Sally.

Thus the reaſonableneſs of this old Opinion may be vindicated, but the certainty of it reſts upon ſtronger proof. Mr *Cowper*, to whoſe happy Induſtry we owe the Confirmation of many Antient Diſcoveries, and the benefit of ſome new ones, has the honour to re-eſtabliſh this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Artery* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd thoſe Branches of the *Umbilical* Veins, which went from that *Cotyledon* to the *Navel* of the *Fœtus*; which with a part of the *Uterus* he keeps prepar'd by him.

It wou'd be a weak objection, to alledge that the Obſervation and Experiment being made on the *Uterus* of a *Cow*, the inference wou'd not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous*;

ſince ev'ry one of theſe *Cotyledones*, or *Uterine Glandules*, is in all reſpects a little *Placenta*, and all the difference between 'em is in number, name, and magnitude. Why *Ruminants* differ in this particular from other *Viviparous* Animals, is beſide the ſubject of our preſent Enquiry. But the great Flux of Blood which conſtantly follows upon drawing the *Placenta* from Women (which is frequently ſo great as to coſt 'em their Lives) is as plain a demonſtration to Reaſon of the *Continuity* of the Veſſels, as Mr *Cowper*'s Experiment is to the Eye.

I have heard it objected by very learned men, that if there were ſuch a *Continuity* of Veſſels, and ſuch *Transfuſion* of Blood, the *Fœtus* muſt neceſſarily periſh thro loſs of Blood, upon the ſeparation of the *Placenta* from the *Uterus*, but that on the contrary no viſible flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which condition it may be kept alive ſome hours. To this it may be anſwer'd, that the Circulation in the *Fœtus* being deriv'd from the Mother, may be ſuppos'd wholly to ceaſe upon the cutting off the communication between 'em, till it is again renew'd more forcibly by *reſpiration*. But if we allow the Motion already impreſs'd upon the Blood to be ſufficient to keep it going a little while, yet it muſt needs be ſo exceeding languid, that the meer reſiſtance of the external Air muſt be more than enough to hinder any Efflux of Blood from a *Fœtus* before Reſpiration. How long Life may be preſerv'd without an *actual* Circulation of the Blood, is a queſtion not of this place. But we have been convinc'd by many and notorious Obſervations and Experiments, that Life has been recover'd a long time after all tokens of Reſpiration, Circulation, or even Life it ſelf have diſappear'd, ſo that we can't think the firſt ſolution either impoſſible or improbable.

I expect to be told, that in the early days of *Geſtation* in *Viviparous* Animals there is no *Placenta*, or any Adheſion of the *Umbilical* Veſſels to any part of the *Mother*, and conſequently no ſuch *Transfuſion*; and that in *Oviparous* there is no *continuity*, or *communication* of Veſſels of any kind, during the whole time of *Incubation.*

But theſe Objections carry neither the Weight nor Difficulty along with 'em, that they may be ſuppos'd to do; for in thoſe days there is neither *Blood* nor *Blood Veſſels*, and conſequently there can be no *Circulation* of the Blood; and the *Embryo*, of what Species ſoever, is no more than a *Vegetable* at that time; nor does the *Fœtus* of any *Viviparous* Creature enjoy any *Circulation*, or ſhew any ſigns of Animal Life, till after thoſe Veſſels, as well as others requiſite to the Circulation, are compleated.

It muſt be confeſs'd, that *Oviparous* Animals are denied the Benefit of this Communication: But that want is ſufficiently compenſated by a peculiar Mechaniſm, which directly anſwers the ends of *Reſpiration*, and the *Preſſure* of the *Atmoſphere* upon the *Fœtus*. There is at the *Obtuſe* end of an Egg a ſmall Cavity fill'd with Air, which is the Succedaneous Inſtrument to the *Reſpiratory* Organs. For as ſoon as the Contents begin to be warm'd by the *Incubation* of the Hen, or *any analogous* Heat of *Furnace* or *Dunghil*, the ſeveral Humours of the Egg require a *Fermentative* Motion, and the *Air* contain'd in the *Cavity* or *Veſicle* at the *obtuſe* end of the Egg is rarefied, and the Veſicle extended and enlarg'd, and conſequently the other contents are compreſt; to which the *Fermentative* Motion naturally reſiſts. But both Bodies being as well *compreſſible* as *dilatable*, and both having an *Expanſive* Motion impreſt upon 'em by *Incubation*, the compreſſion and renitency will be mutual; but varied in degree, according as either, thro the variation of Circumſtances, ſhall prevail. By this means, an Alternation of Compreſſion and Dilatation will be produc'd in both anſwering the *Reſpiratory* Motion, by which a Motion will be communicated, which, as ſoon as the Organs by which it ſhou'd be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory.*

Fabritius ab Aquapendente, and after him our Great Dr *Harvey*, have aſſign'd divers uſes to this Cavity or Air Veſicle, the Extravagance of which have perhaps deterr'd others from enquiring ſo much into the Uſe, as the importance of it requir'd. But tho I can't agree to that *Perſpiration*, *Refrigeration*, and *Reſpiration*, which they make it the Inſtrument of, yet perhaps the *Air*, that was incloſ'd in that *Cavity*, may thro the augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at laſt ſo great as to occupy half the Shell) break the *Membrane*, which ſeparated it from the *Pullus*, and thereby give ſo much *Reſpiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell, and with it give an Addition of Strength to enable it to break the Shell. But how it ſhou'd reſpire ſooner is to me inconceivable.

There are many Problems of great ſeeming difficulty, the ſolutions of which flow naturally from what has been laid down here: But intending to proſecute this Subject farther, and to treat of the Impediments of Reſpiration, and the conſequences of Reſpiration obſtructed or intermitted, I ſhall reſerve 'em for that opportunity, and content my ſelf here to attempt the *Harveyan* Problem only, which has given abundance of Authors ſo much perplexity.

That incomparable Philoſopher enquires, *Why a* Fœtus, *taken ont of the* Uterus *with the* Membranes *entire, ſhall live in Water ſome hours without communication with the* external Air; *whereas if it be taken out and ſuffer'd once to breath, it can't afterwards ſurvive a moment without the benefit of* Reſpiration.

Granting the Fact to be as he has deliver'd it, which yet is not ſo in all caſes, the main difficulty is grounded on a Miſtake, which from the ſtating of the Queſtion I find this Great Man to have ſlipt into. For he thinks, that a *Fœtus* is ſooner ſuffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted ſomething which render'd it more periſhable. *Idem tamen ſecundis exutus*, (ſays he) *ſi ſemel* aerem *intra* Pulmones *attraxerit, poſtea ne momentum quidem temporis abſq; eo durare poſſit, ſed confeſtim moriatur?* And preſently after, *Siquidem* con-

Harv. de Gen. Anim. Cap. de Partu.

conſtat, fœtum, poſtquam eum ſemel *hauſerit*, citius *ſuffocari*; *quam cum ab* illo prorſus *accebatur*. The Dr, obſerving a *Fœtus* to live longer without Reſpiration, and to diſpence better with the want of Air while included in the Membranes entire, than it cou'd afterwards; infers thence, that the Air does in the firſt Act of Inſpiration impreſs upon the Lungs ſome quality, which renders it ever after more indiſpenſably neceſſary. But allowing his Obſervation, I muſt yet deny his Inference to be good: For, deprive a *Fœtus* of means of reſpiring, and then take it out of the Membranes, and it ſhall be as ſoon ſuffocated, as if it had reſpired before. This proves, that this Neceſſity of intercourſe with the Air by way of the Lungs is not the Offsſpring, but the Parent of Reſpiration, and that, that Learned Man was drawn into a Fallacy of *Non cauſa pro cauſâ*.

The reaſon of this Neceſſity is the preſſure of the External Air upon the Surface of the Body, from which it was defended by the interpoſition of the Membranes and the Humours contain'd, which are not ſo compreſſible, as the Body of the *Fœtus* itſelf. So ſoon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmoſphere, the Veſſels and all the Cavities of the Body muſt neceſſarily be ſo compreſs'd, that the Fluids can't have room for Motion, and conſequently the *Fœtus* cou'd have no Life, if Nature had not contriv'd by the Motion of the *Thorax* to remove and admit that preſſure alternately, and thereby to impreſs a Motion on the Fluids, which is the Spring of Life. But this Motion of the *Thorax* being any way ſuppreſs'd, the equal preſſure of the Atmoſphere on all parts occaſions a total Ceſſation of Motion, which is Death.

I ſhall proſecute this Subject no farther now, nor trouble the Reader with any Apology, for diſſenting from thoſe great Men herein named: Becauſe, I hope, I have done it with Modeſty, and all the Reſpect due to ſo great Authorities, and have aſſign'd nothing which is not matter of Fact uncontroverted, or deduc'd from it by plain Mechanical Neceſſity.

III. *The*